EFFECT OF INCISING AND PRESERVATIVE TREATMENT ON SHEAR STRENGTH OF NOMINAL 2-INCH LUMBER[1]

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ABSTRACT

This study evaluated the effects of pretreatment incising of dry lumber and preservative treatment on the shear strength of 1980 pieces of 2 × 4 dimension lumber (nominal 50 mm × 100 mm × 3.6 m long). Three species groups (Douglas-fir, Hem-Fir. and Spruce-Pine-Fir-South) and two commercially produced machine-stress-rated grades per species group were tested in torsion to determine their shear strength. Incising and preservative treatment produced significant reductions in the average shear strength of Douglas-fir, Hem-Fir, and Spruce-Pine-Fir-South dimension lumber. These effects need to be addressed through the development of more appropriate design values for uses of preservative-treated wood of these species when shear is a governing factor. An adjustment factor of 0.70 is proposed for incised and preservative-treated nominal 2-inch lumber.

Keywords: Incising, preservative treatment, shear strength, MSR lumber, grade, torsion.

INTRODUCTION

Preservative treatment of many thin sapwood species poses a major challenge. Incising has long been used to increase the amount of transverse area exposed to potential preservative flow. The longitudinal pathways exposed on these transverse faces are far more receptive to preservative flow than are the radial or tangential surfaces (Morris et al. 1994). As a result, incising improves preservative penetration to the depth of the incision. For many years, incising was used primarily on large timbers, such as railroad ties, or on utility poles. The incisors used widely spaced, large teeth with relatively little concern for the

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appearance of the unfinished product or possible effects on mechanical properties of the wood (Morrell and Winandy 1987). The emergence of markets for preservative-treated dimension lumber for the "do-it-yourself" user encouraged the development of incisors that employed smaller, more closely spaced teeth (Lebow and Morrell 1993; Morns et al. 1994; Winandy et al. 1995). The zone of enhanced treatment around individual incisions is relatively small, and thus the incisions need to be denser (Smith and Morrell 1991). The result has been an increased consumer acceptance of incised wood. Incising, however, is not without its drawbacks. The process reduces the cross-sectional area of the wood member (Winandy et al. 1995). This was of relatively little concern when incised products were large timbers or poles, but can become critical in smaller dimension lumber now used for structural applications.

Incising is not a precisely defined or standardized process. American Wood-Preservers' Association (AWPA) treatment specifications require incising, but because the standards are truly performance based, as long as the minimum treatment penetration requirements are met, the treated product meets the standard (AWPA 1996). The AWPA Standards do not define acceptable patterns or set required incising depths. However, recent improvements in incisor technology have tended to "normalize" the equipment used to incise nominal 2-inch lumber, especially with respect to tooth size and pattern densities. Thus, based on our previous reviews of existing incising practices (Morrell and Winandy 1987; Winandy et al. 1995), two representative incising patterns and two incising depths were selected for intensive study.

Most research about the effects of incising on mechanical properties concentrates on bending. A number of studies have shown that incising can have effects on bending strength and stiffness (Perrin 1978; Lam and Morris 1991), and design codes (CSA 1989; AFPA 1997) recommend incising factors (C_i) to adjust mechanical properties of incised, preservative-treated wood. In most instances, bending governs design; however, shear can govern design under certain conditions. The effect of incising and treatment on shear strength of large timbers and glulam was found to range from -7% to -15% (Rawson 1927; Harkom and Rochester 1930; Schrader 1945). The effect of incising on shear strength, especially in dimension lumber, has received little attention, but the potential effects are of concern in Hawaii, where the extreme risk of Formosan termites has led to a statewide code requirement that all interior and exterior wood used in buildings be pressure-treated with preservatives. Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) is the preferred species used in Hawaii, but incising is required to achieve acceptable preservative treatment of this species (AWPA 1996).

There is considerable discussion concerning the relative merits of various test methods to determine the shear strength of full-size structural lumber (Soltis and Rammer 1994; Rammer et al. 1996; Riyanto and Gupta 1998). A bending test used for determining shear strength has shear, bending, and compression-perpendicular stresses. Also, bending tests produce shear failures in only 30% to 50% of test specimens, resulting in a need for many specimens in order to develop an adequate data base on shear strength (Riyanto and Gupta 1998). On the other hand, torsion tests of nominal 2 × 4 lumber produce shear failures in all cases, and there is no interaction from other stresses (compression perpendicular to grain and bending stresses) (Boresi et al. 1993; Heck 1997; Riyanto and Gupta 1998). Also, torsion testing maximized the utility of our limited number of test specimens. Since the objective of the study was to determine the effect of incising and treatment on shear strength, and not to determine the exact value of the shear strength, torsion testing was used to determine the shear strength. The results provide a relative guide to the potential influence of incising and treatment practices on shear strength.

MATERIALS AND METHODS

This experiment was part of a larger study that evaluated the effects of incising on treatment outcome, bending strength, and shear strength. Mill-run dimension lumber consisting of 648 to 660 samples each of Douglas-fir, Spruce-Pine-Fir-South (a commercial mixture of *Picea engelmannii* Parry ex Engelm. *Picea sitchensis* (Bong.) Carr., *Pinus contorta* Douglas ex Loud., and *Abies* spp.), and Hem-Fir (a commercial mixture of *Tsuga heterophylla* (Raf.) Sarg. and *Abies* spp.) (nominal 50 mm × 100 mm × 3.6 m long) were obtained from commercial suppliers. The lumber was dry (moisture content < 19%), and each species group was segregated into high and low stiffness-strength classifications based on machine-stress-rated (MSR) grades. The modulus of elasticity (MOE) of each board was then nondestructively reassessed by transverse vibration techniques. These results were used to sort the boards within each species/grade group into stratified E-matched treatment groups that contained nearly equal relative stiffness-strength distributions.

The boards were then incised to a density of either 7,000 or 8,500 incisions per m^2 with one of two Protomech incisors (LRH Inc., Corvallis, OR). The high density incisor had teeth that were knife-like, while those on the lower density incisor were more scallop-shaped. An incision depth of 10 mm was tried for Hem-Fir initially. However, this depth resulted in extensive tearing and stripping of the dry wood. Therefore, only four groups of Hem-Fir were incised to 10 mm. Incision depths were 5 or 7 mm for all other specimens. While the 10-mm depth might have been possible with green Hem-Fir lumber, the systematic sorting into dry E-matched groups prior to incising precluded this prospect. The incised boards were then commercially treated to 6.4 kg/m^3 (the recommended ground contact retention) with one of three preservatives: chromated copper arsenate (CCA) (Type C), ammoniacal copper zinc arsenate (ACZA), or ammoniacal copper quaternary (ACQ) (Type B) (AWPA 1996) (Table 1). Following treatment, the boards were cut into three sections: 1.8, 1.2, and 0.6 m long. The 0.6- and l.8-m-long sections were used to assess preservative treatment and bending strength, respectively, and the results have been reported elsewhere (Anderson et al. 1997; Winandy and Morrell 1998). The 1.2-m-long sections were air-seasoned, and then a single 0.9-m-long section containing the clearest component was cut from each sample. These sections were conditioned to a stable moisture content (about 13%) at 70% relative humidity and 23°C and then tested in torsion to determine shear strength.

Testing apparatus

The torsion machine that was used in this test had a drive mechanism for an angular displacement with a moveable clamp at one end and a stationary clamp at the other end. The clamps (51-mm depth) gripped the specimen without slipping or damaging the test section, but they still allowed the specimen to move longitudinally during twisting when torque was applied. The clamps were placed symmetrically about the central point of the cross section of the specimen, twisting the specimen about its neutral longitudinal axis (Fig. 1). A constant rate of twisting was used. which produced shear failure in 5 to 20 minutes (ASTM 1997).

A shear span of 5 times the width (i.e., 5 × 89 mm) was used for the torsion test. The overall length of the torsion test specimen was 902 mm, which included twice the width (178 mm) on each side of the shear span to exclude the end effects and 51 mm on each side for clamping. The specimen length also met the requirements of ASTM D 198 (ASTM 1997), which requires the length of the torsion test specimens to be at least 8 times the width.

Stress calculations

ASTM D 198 (ASTM 1997) provides two equations for determining the mimimum shear stress in the torsion test. The following equa-

TABLE 1. *Effect of incision depth, density, and preservative treatment on shear strength of Douglas-fir, Spruce-Pine-Fir-South, and Hem-Fir lumber.*

	Incision				Higher grade[a]			Lower grade[a]		
Species group	Depth (mm)	Density (incisions/m^2)	Preservative treatment[b]	Replicates	Specific gravity	Shear strength (MPa)	Ratio[c]	Specific gravity	Shear strength (MPa)	Ratio[c]
Douglas-fir	—	—	—	55	0.513	12.14 a	—	0.456	10.27 a	—
	—	—	ACZA	55	0.520	11.00 b	0.91	0.461	10.00 a	0.97
	5	7,000	ACZA	55	0.522	8.24 d	0.68	0.463	8.45 bc	0.82
	5	8,500	ACZA	55	0.518	9.27 c	0.76	0.452	8.93 bc	0.87
	7	7,000	ACZA	55	0.522	6.21 e	0.51	0.460	5.48 cd	0.53
	7	8,500	ACZA	55	0.517	7.41 d	0.61	0.459	7.41 e	0.72
Spruce-Pine-Fir-South	—	—	—	66	0.473	10.89 a	—	0.419	11.86 a	—
	5	8,500	CCA	66	0.471	9.17 b	0.84	0.427	7.86 b	0.66
	5	8,500	ACQ	66	0.462	7.24 c	0.66	0.430	7.17 c	0.60
	7	7,000	CCA	66	0.470	6.48 d	0.59	0.435	6.83 c	0.58
	7	7,000	ACQ	66	0.469	5.65 e	0.52	0.428	5.17 d	0.44
Hem-Fir	—	—	—	36	0.473	12.03 a	—	0.422	10.62 a	—
	5	7,000	CCA	36	0.473	7.86 bcd	0.65	0.430	7.62 bcd	0.72
	5	7,000	ACZA	36	0.470	7.31 cd	0.61	0.433	7.34 cd	0.69
	5	8,500	CCA	36	0.483	8.17 b	0.68	0.434	8.48 bc	0.80
	5	8,500	ACZA	36	0.488	8.00 bc	0.67	0.439	7.89 bcd	0.74
	7	8,500	CCA	36	0.483	7.17 bcd	0.60	0.423	8.34 bc	0.79
	7	8,500	ACZA	36	0.483	7.41 bcd	0.62	0.435	7.76 bcd	0.73
	10	7,000	CCA	36	0.484	5.76 e	0.48	0.432	5.31 e	0.50
	10	7,000	ACZA	36	0.491	5.24 e	0.44	0.437	5.14 e	0.48

[a] Lower grade lumber had on average E of 12.4, 10.4, and 10.4 GPa for Douglas-fir, Spruce-Pine-Fir, and Hem-Fir, respectively. Higher grade material E values were 15.2, 13.1, and 13.8 GPa, respectively. Values followed by the same letter for a given species do not differ significantly at $\alpha < 0.05$.

[b] ACZA = ammoniacal copper zinc arsenate; CCA = chromated copper arsenate; and ACQ = ammoniacal copper quaternary.

[c] Ratio of shear strength of incised, treated specimens relative to unincised, untreated control.

tion, which gives the larger value (shear stress at the middle of the wide side), was used to shear strength in the current study:

$$\tau = \frac{8\gamma T}{w\mu t^2} \qquad (1)$$

where

τ = shear stress (MPa)

γ = 1.9005 = St. Vienant constant from Table X3.2 (ASTM 1997)

T = maximum torque (kg-mm)

w = width of the specimen (mm)

μ = 3.889 = St. Vienant constant from Table X3.2 (ASTM 1997)

t = thickness of the specimen (mm)

Analysis

The effects of incising and treatment on torsional shear strength were evaluated by computing the ratio of the average shear strength for some particular incised and treated group to the average shear strength for its E-matched unincised and untreated control. Because of the limited number of replicates and the ongoing debate on the influence of test methodology on shear strength evaluation, no attempt was made to evaluate the effects of incising and treatment across the shear strength distribution.

RESULTS AND DISCUSSION

Incising significantly reduced average shear strength of all three species groups tested in torsion (Table 1). These effects were a function of species group, treatment, MSR-grade,

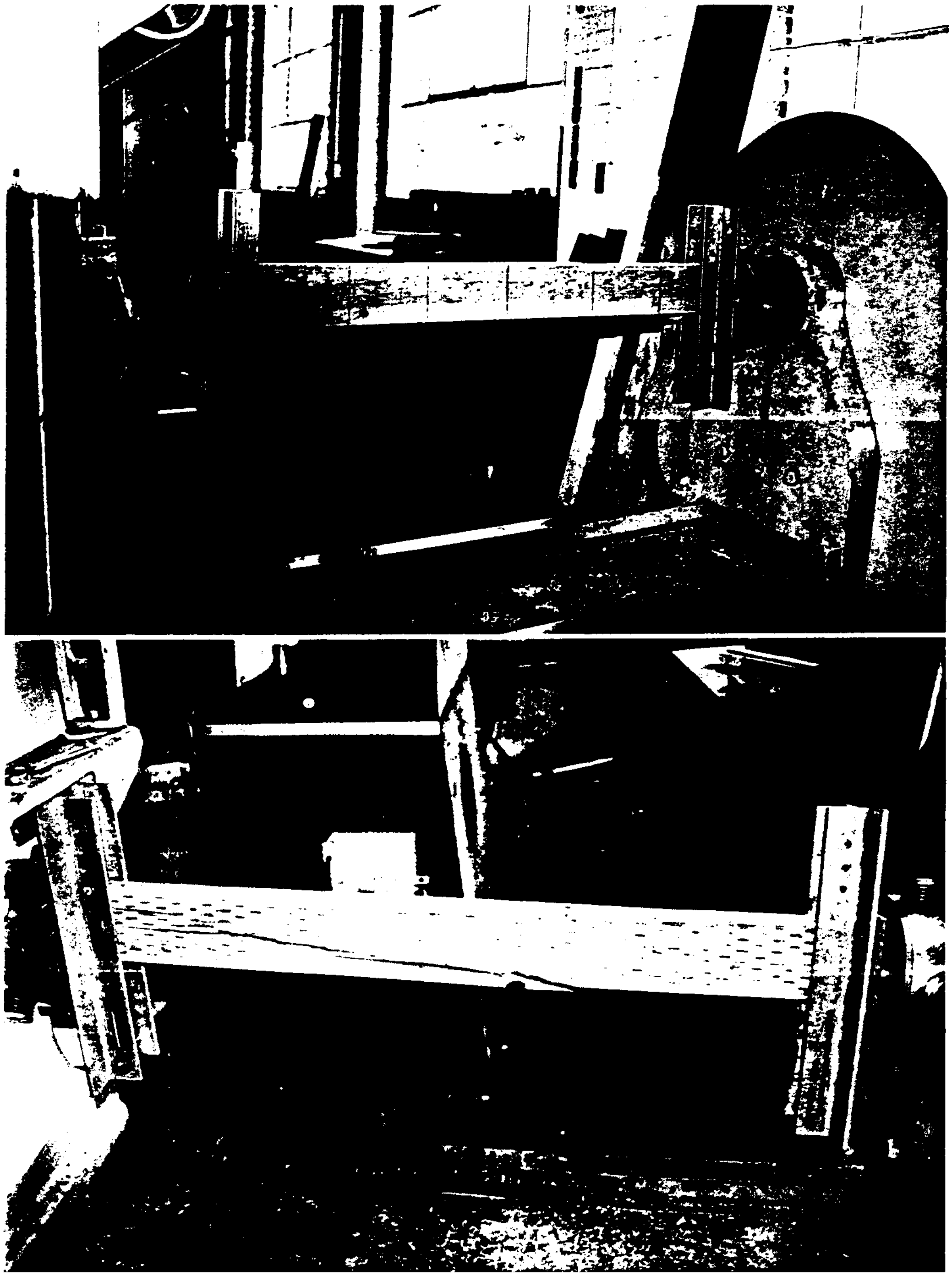

FIG.1 Apparatus used to evaluate torsional shear of test samples (A) and a sample at the conclusion of a test (B).

incision depth, and incision density. The geometry of the incising tooth itself also seemed to influence reductions in shear strength. The incising effects discussed in the following sections specifically apply only to nominal 2-in., MSR-graded lumber. While some inference may be appropriate to visually assigned grades, these companions should be done judiciously because the within-grade variability in MOE of MSR-lumber is significantly less than (e.g., nearly half) that of visually assigned grades of lumber (Brown et al. 1997).

Douglas-fir

ACZA treatment alone (without incising) significantly reduced shear strength of the higher grade lumber, but not of the lower grade material (Table 1). Strength losses for incised and treated material, calculated as the ratio with the unincised and untreated control, were always less in the lower grade materials than in the higher grade, although the differences were sometimes slight. The depth of incision at a given density also significantly affected shear in both grades, with shear strength decreasing with increased incision depth. Average shear strength was also different between the two incising densities at the same depth, although the effects were the reverse of those expected. Shear strength appeared to be more affected by the lower density pattern (7,000 incisions per m^2), but differences in tooth design may have influenced these results. The knife-like tooth on the higher density incisor (8,500 incisions per m^2) is more likely to slice through the wood with minimal damage, while the scallop design of the lower density incisor is more likely to crush or tear fibers, thereby reducing shear strength further. The specimens that were incised with the scallop-shaped teeth to a depth of 7 mm had an average shear strength that was 52% of the unincised control.

Spruce-Pine-Fir-South

As with Douglas-fir, incising significantly reduced average shear strength regardless of incision depth, incision density, or chemical treatment (Table 1). Once again, incision depth exerted a greater effect on shear strength than did incision density, although the differences may actually reflect differences in tooth geometry between the patterns. The combination of the deeper incisions and the less dense pattern (7,000 incisions per m^2) resulted in maximum strength loss, particularity with ACQ. Average shear strength declined most substantially with the ACQ treatments, and these differences were significant for each incision density/depth combination. The reason that ACQ had more effect on shear strength than did CCA is unclear. In studies related to kiln-drying, CCA tended to affect bending strength more than did ammonia-based preservatives such as ACZA (Winandy 1995). These differences have been attributed to the acidic nature of CCA in which the hexavalent chromium is more reactive with the wood than is an ammonia-based system. The possible effects of ammonia on shear merits further study, because similar effects have been noted for bending strength with ACQ-treated southern pine *(Pinus* spp.) (Barnes et al. 1993), with ammoniacal copper citrate-treated southern pine (Winandy and Lebow 1997), and with incised and ACQ-treated Spruce-Pine-Fir-South (Winandy and Morrell 1998).

Hem-Fir

Some boards of this species group were actually incised to a depth of 10 mm, rather than 7 mm (Table 1). As with the other two species groups, average shear decreased significantly in incised lumber, and this effect was greatest with the deep incisions applied at the lower density. Unlike Spruce-Pine-Fir-South, however, there was no significant difference between the effect of the two preservative treatments (CCA and ACZA) regardless of incision density, depth, or MSR-grade of wood. Once again, the deeper incisions applied at the lower density (7,000 incisions per m^2) had the greatest negative effect on average shear strength. The absence of a differential chemical effect suggests that additional studies are needed on the sensitivity of shear strength of various species to ammonia-based systems to explain recurring differences between ACZA and other ammonia-based systems.

Implications

As noted, these results apply only to MSR-graded, nominal 2-inch lumber. Further, shear is less often a governing factor in building design than is bending strength. If our results of shear strength derived from torsion tests are applicable to design values derived from block-shear results, then design values for shear should be adjusted when nominal 2-in., incised, preservative-treated wood is used. In this study, the incisions were made on dry lumber, whereas in normal practice, many testers purchase wet-sorts from dry kilns that have moisture contents between 17% and 40%. Drying this green, incised lumber below the fiber saturation point prior to treatment reduces potential effects on appearance. The incisions tend to close and become less noticeable as the wood seasons further prior to treatment. The incisions in our study tended to cause more surface damage than would be seen in commercial practice, and therefore our results should be considered as worse-case for the species group/incision/preservative treatment combinations we studied. These results remain relevant, however, since the incising requirement in Standard C2 of the AWPA does not specify wood conditioning at the time of incising nor does it address maximum/minimum incision depths or densities (AWPA 1996). Our results suggest that these factors deserve further attention within AWPA Standards to ensure uniformly treated wood that can provide acceptable engineering performance. A design adjustment for shear would depend on the species-grade combination being considered (Table 2). If a single design adjustment for shear were desired for simplicity, a shear strength adjustment factor of 0.70 might be appropriate, based on an average "incising effect" for incised and preservative-treated, nominal 2-inch material as derived from Table 2.

TABLE 2. *Proposed design adjustment for incised and treated nominal 2-inch lumber in shear.*

Species	MSR-Grade[a]	
	Lower	Higher
Douglas-fir	0.75	0.70
Spruce-Pine-Fir-South	0.65	0.70
Hem-Fir	0.75	0.65

[a] MSR = machine stress rated. Lower MSR-grades have $E \leq 12.75$ GPa. Higher MSR-grades have $E > 12.76$ GPa.

CONCLUSIONS

Incising and preservative treatment produced significant reductions in the average shear strength of Douglas-fir, Spruce-Pine-Fir-South, and Hem-Fir dimension lumber when tested in torsion. Control of these effects for dry incised lumber should be addressed through changes in AWPA Standards. Further, the development of appropriate design adjustments should be considered for incised and preservative-treated wood when shear is the governing design factor. Based on results of torsional shear tests, the incising effect varied from 0.65 to 0.75 depending on the species and MSR-grade. An adjustment factor for shear of 0.70 is proposed for incised and preservative-treated nominal 2-in. material.

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